

MODELING AND OBSERVATION OF THE WATER ISOTOPIC RATIOS ON MARS: APPROACH TO THE CLIMATE CHANGES. Kuroda, T.¹, Sagawa, H.², Kasai, Y.², Terada, N.¹, and Kasaba, Y.¹, ¹Department of Geophysics, Tohoku University (6-3 Aramaki-aza-Aoba, Aoba, Sendai, Miyagi, 980-8578 Japan, tkuroda@pat.gp.tohoku.ac.jp, teradan@pat.gp.tohoku.ac.jp, kasaba@pat.gp.tohoku.ac.jp), ²National Institute of Information and Communications Technology (4-2-1 Nukui-kita, Koganei, Tokyo, 184-8795 Japan, sagawa@nict.go.jp, ykasai@nict.go.jp)

Introduction: Though the current Mars is a dry planet, there are many topographic evidences of past liquid water flow [1-4]. Some of the liquid water is thought to have escaped into space, while some seems to have moved to the polar regions and underground [5,6]. For the investigations of the history and movement of water, detections of the isotopic ratios in water molecules (e.g. D/H and $^{18}\text{O}/^{16}\text{O}$) in the atmosphere and on/under the surface of Mars should provide important hints.

There are two main significances in the detections of the water isotopic ratios. First is for the investigation of the age of water. D (deuterium) is heavier than H, and the vapor pressure of HDO is lower than that of H_2O . They cause that H tends to be escaped easier than D, which results in the increase of D/H ratio with time. Second is for the visualization of the physical processes on the water cycle, as has been done for the terrestrial atmosphere [7]. On Mars, such a mapping may be expected to reveal the water cycle in current Mars environment, especially the moving in and out between surface/underground and atmosphere as observed [ex.8]. Isotopic ratios will be the markers to trace the movement and history of water on Mars.

At present the observations of water isotopic ratios on Mars have only been done from the ground-based telescopes and the Herschel Space Observatory. The globally-averaged D/H ratio in current Mars atmosphere is 4~6 times as SMOW (Standard Mean Ocean Water on Earth, $\sim 1.56 \times 10^{-4}$) [9-11]. It is also reported that there are large spatial variances of the D/H ratio, from 2 to 8 times of SMOW [12]. The 3-dimensional simulation of the D/H ratio of water using a MGCM (Mars General Circulation Model) has also been done [13], which shows qualitatively consistent results in latitudinal distributions with the recent observations [14]. But curiously, the observed $^{18}\text{O}/^{16}\text{O}$ ratio on Mars is almost the same as SMOW ($\sim 2.01 \times 10^{-3}$) [15,16], though the escape probability of ^{18}O is smaller than ^{16}O [17]. It is unknown why the $^{18}\text{O}/^{16}\text{O}$ ratio does not increase, possibly due to some systems for mitigating or reversing fractionation of $\text{H}_2\text{O}/\text{CO}_2$ on surface.

Observational approaches: Detections of the isotopic ratios for the investigation of the climate changes are considered in future Japanese Mars missions, such as using the sub-millimeter sounder FIRE (Far Infra-Red Experiment) [18]. The advantage to use

the sub-millimeter wavelength is that the retrieval is not affected by atmospheric dust, and we can observe the field of temperature and atmospheric compositions regardless of the dust conditions. Our current plan with FIRE is to observe H_2O and HDO simultaneously using the wavelength band of 550-620 GHz (see Figure 1). The simulated observational sensitivity of water vapor and D/H ratio are shown in Table 1. We are also considering to observe H_2^{18}O using its absorption line nearby.

MGCM simulation: We are starting the simulations of the movement and cycle of water in the atmosphere of Mars using the DRAMATIC (Dynamics, Radiation, Material Transport and their mutual Interactions) MGCM. It is previously known as CCSR/NIES or CCSR/NIES/FRCGC MGCM, which is based on a spectral solver for the three-dimensional primitive equations [21]. In this simulation the horizontal resolu-

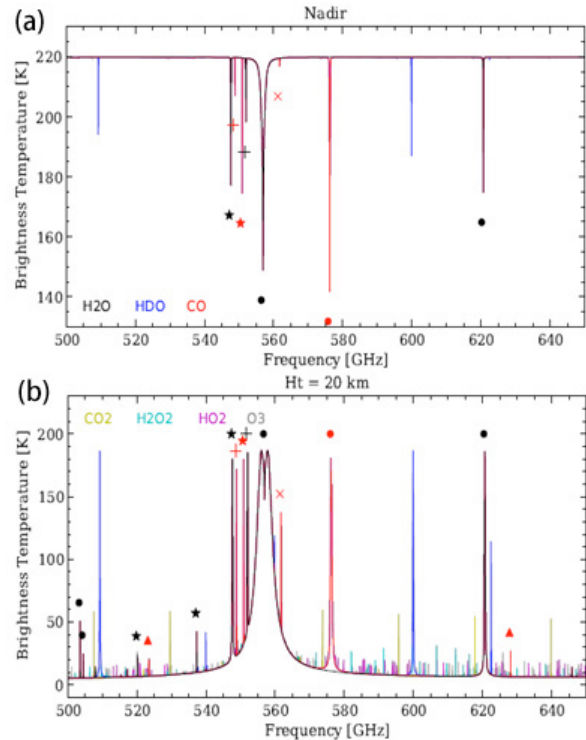


Figure 1: Simulated sub-millimeter spectra of Mars atmosphere assuming the geometries of (a) nadir and (b) limb/tangential height of 20 km [18].

Geometry	Target	Altitude range [km]	Accuracy	Vertical resolution [km]
Nadir (25s integration)	Water vapor	0~20 20~40	2~5 % 1~10 %	6 6~10
	D/H ratio	0~40	0.5~3 [×SMOW]	10~20
Limb (0.5s integration)	Water vapor	0~40 40~60 60~80	<1 % 1~10 % 10~30 %	3 3~6 6~8
	D/H ratio	0~20 20~40	0.1 0.2~1 [×SMOW]	3 3~4

Table 1: The expected sensitivity of the observations of water vapor and D/H ratio by FIRE/MELOS [18] calculated under the condition of ‘warm scenario’ of Mars Climate Database v4.1 [19,20].

tion is set at about $5.6^\circ \times 5.6^\circ$ (~ 333 km at equator), and the vertical grid consists of 49 σ -levels with the top of the model at about 100 km. Realistic topography, albedo, thermal inertia and roughness [22] data for the Mars surface are included. Radiative effects of CO_2 gas (considering only LTE) and dust, in solar and infrared wavelengths, are taken into account. In the results we show here the seasonal and latitudinal changes of dust opacity are defined with the ‘MGS Scenario’ of the Mars Climate Database v3 [19,20].

The water cycle scheme is already implemented in the MGCM [23] (see Figure 2), but now we have some updates from [23]. Based on the idea of [24], the water ice clouds are considered to be formed with dust particles as nuclei. Then the radius of the water ice particles (r_c) is defined as follows:

$$r_c = \left(\frac{M_c}{(4/3)\pi\rho_i N} + r_0^3 \right)^{1/3} \quad (1)$$

where M_c is the mass of water ice in the layer, ρ_i is the density of water ice (917 kg m^{-3}), N is the number of dust particles in the layer, and r_0 is the radius of dust particles. N and r_0 are defined as follows:

$$N = \frac{M_d}{(4/3)\pi\rho_d r_0^3} \quad (2)$$

$$r_0(z) = r_{z0} \exp(-z/h) \quad (3)$$

where M_d is the mass of dust in the layer, ρ_d is the density of dust (2500 kg m^{-3}), r_{z0} is the radius of dust at 0 km height ($0.8 \text{ }\mu\text{m}$), and h is the scale height of dust particle size (18 km).

For the definition of turbulent flux F [$\text{kg m}^{-2} \text{ s}^{-1}$], the amount of water vapor sublimed from the surface water ice, we have now introduced the evaporation efficiency β which should depend on the surface physicality and moistness. The formula of turbulent flux can be written as follows:

$$F = \beta \rho C_E |v_1| (Q_{\text{sat}} - Q_1) \quad (4)$$

where ρ is the atmospheric density, C_E is the bulk coefficient which is a function of surface roughness and atmospheric instability, v_1 is the wind velocity at the lowest layer, and Q_{sat} and Q_1 are the mass mixing ratio of water vapor at saturation and the lowest layer, respectively. In the terrestrial case the value of β is 1 on the pure continental ice and less (between 0 and 1) when the surface is not pure ice. Here we set β as 0.01 for all places, considering the cover of dust and/or CO_2 ice cap on the surface water ice.

Recently the existence of very large supersaturation ratio (~ 10 times) of water vapor in the middle (around ~ 40 km height) atmosphere on Mars has been indicated by the observations by SPICAM onboard Mars Express [25]. Such a large supersaturation should make a great impact on the current water cycle, consequently on the atmospheric chemistry and escape processes also, but has not reproduced by current MGCMs with typical water cloud schemes. Our MGCM does not consider the effects of supersaturation in the formation of water ice clouds, but here we also did a simple experiment considering the supersaturation, just allowing the water vapor abundance in the atmosphere up to 10 times as the saturation amount.

Moreover, we have implemented the isotopic fractionation for HDO and H_2O in our MGCM. Based on the idea of [13], we introduced the fractionation factor α , which represents the relative concentration of HDO in ice onto that in the surrounding vapor at thermodynamic equilibrium given by [26].

$$\alpha = \frac{(\text{HDO}/\text{H}_2\text{O})_{\text{ice}}}{(\text{HDO}/\text{H}_2\text{O})_{\text{vap}}} = \exp\left(\frac{16289}{T^2} - 9.45 \times 10^{-2}\right) \quad (5)$$

Here we set that relative concentration of HDO in ice and vapor in the atmospheric layer is always kept to α when the phase change occurs, as the Rapid isotopic Homogenization (RH) case in [13]. When the surface water ice sublims, we set that the relative concentration of HDO in the sublimed vapor is $1/\alpha$ against that in the surface ice.

Preliminary results of the MGCM: We made the numerical simulations for two cases, with and without the consideration of supersaturation (up to 10 times) as described above. For both cases, the calculations start-

ed from the ‘dry’ isothermal state without water vapor/ice in atmosphere and on surface except permanent water ice cap in the north of 80° N, and have been done for 20 Martian years. The isotopic ratio of the

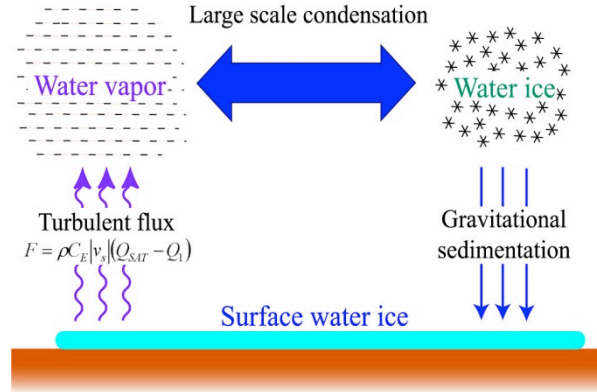


Figure 2: Schematic features of the water cycle scheme [23].

permanent north polar water ice cap is set to 5.6 wrt. SMOW along with the observed standard value on Mars [4].

Figure 3 shows the water vapor column density for 8-20 Martian years from the initial state for both cases. There are clear differences in the amount and time change of water vapor distributions, especially the higher value in low-latitudes with supersaturation is outstanding.

Figure 4 shows the HDO/H₂O ratio in the water vapor column for both cases. The seasonal-latitudinal distributions are qualitatively consistent with the preceding study [13]. The value becomes higher with supersaturation, and decreased with time in both simulations.

Summary and future plans: We are starting the investigations of water cycle and movement on Mars in connection with its climate changes. One of our approaches is the development of the sub-millimeter sounder FIRE for the detailed observations of the distributions of water and its isotopic ratios from a Mars orbiter. In parallel with that, we are developing the DRAMATIC MGCM for the theoretical studies of water cycle including the isotopic fractionations on Mars. The design of FIRE is in progress toward the launch of the next Japanese Mars orbiter(s) planned in early 2020s. Moreover, we have implemented the water cycle and HDO/H₂O fractionation into the DRAMATIC MGCM, and have got preliminary results which are qualitatively consistent with the observations [27] and preceding studies [13,24]. We have also shown the potential impact of the large supersaturation as recently observed [25] on the water cycle.

We have a lot of future plans for the development of the DRAMATIC MGCM. At first, it still does not have the radiative effects of water ice clouds, which should affect on the water cycle dramatically as shown in a preceding simulation study [28]. We are going to

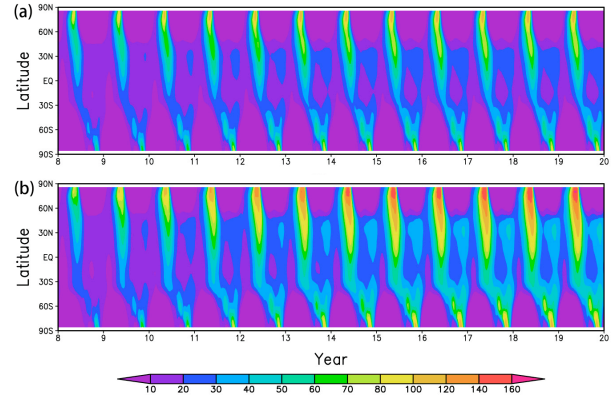


Figure 3: Zonal-mean water vapor column density [pr.μm] simulated by DRAMATIC MGCM for 8-20 Martian years from the dry isothermal state, (a) without supersaturation and (b) including supersaturation up to 10 times.

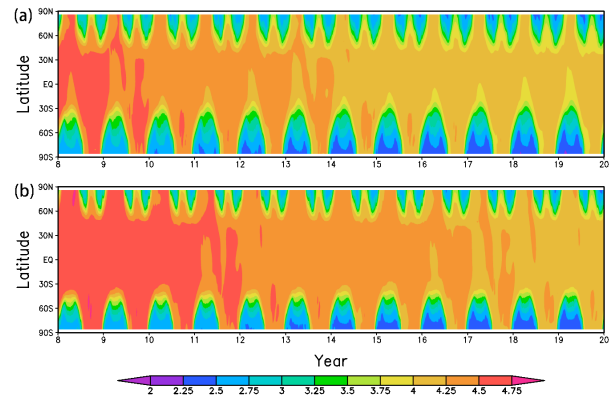


Figure 4: Same as Fig.3, except the HDO/H₂O ratio [wrt. SMOW] in the water vapor column.

implement them quickly into the MGCM, and checking the effects of them on the amount and isotopic ratio of atmospheric water vapor. We also plan to implement the absorption of water by surface regolith and interaction of water transport between subsurface and atmosphere, to investigate the movement of water between ground and atmosphere. In addition, we plan to implement the photochemical processes in the atmosphere and escape of particles coupled with the thermosphere/ionosphere models.

After the above implementations, we will start the simulation of long-term climate change including the effects of atmospheric escape, back to the early Mars. It will be the approach to the change of the environ-

ment of Mars from the ancient ‘blue Mars’. Together with the observations by FIRE, we will investigate the water transport processes from ground to space, with the ultimate goal of understanding the history of the environment and habitability on Mars.

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